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CONTENTS

Page

THE CUSMAP PROGRAM IN THE TONOPAH $1^{\circ} \times 2^{\circ}$ QUADRANGLE

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The U. S. Geological Survey began the study of the geology and mineral resources of the Tonopah $1^{\circ} \times 2^{\circ}$ quadrangle in late 1981 as part of the Conterminous United States Mineral Assessment Program. The project was supported in part by the Nevada Bureau of Mines and Geology. The Tonopah project has utilized a multidisciplinary approach involving geology, geochemistry, geophysics, and studies of mineral deposits, and also included studies of granitic rocks, alteration, linear features, and isotopic dating. Results of these studies will be published in folio format as a series of 1:250,000-scale maps in Geological Survey Miscellaneous Field Studies Map MF-1877. Some larger scale geologic maps and topical studies will be prepared as open-file reports and other publications.

The Tonopah $1^{\circ} \times 2^{\circ}$ quadrangle covers about 19,300 km^2 in south-central Nevada between lat. 38° and 39° and long. 116° and 118°. The quadrangle is within the Basin and Range physiographic province. The ranges constitute about 50% of the total area.

Pre-Tertiary rocks are exposed in nearly all the ranges. Latest Precambrian and Paleozoic rocks are distributed mainly in the eastern two-thirds and the southwestern corner of the quadrangle. Mesozoic sedimentary and volcanic rocks crop out mainly in the northwestern part, and Mesozoic plutonic rocks are exposed only in the central and western parts. Tertiary rocks, found in all the ranges, make up about 85% of the rocks exposed, and include ash-flow tuffs, intermediate and mafic flows, rhyolitic flows and intrusive bodies, and tuffaceous sedimentary rocks. Quaternary basalt flows cover an area along the southeastern edge of the quadrangle.

About 30% of the quadrangle was mapped at a scale of 1:62,500 or larger during the Tonopah project. Areas selected for geologic mapping were chosen after an assessment of existing geologic maps and consideration of resource potential. Areas of new geologic mapping are in the Monte Cristo, Paradise, Toiyabe, Toquima, and Monitor Ranges, the Cedar and Shoshone Mountains, and the Royston Hills.

Gravity and magnetic maps compiled for the Tonopah CUSMAP study combine new data with that from previous compilations. Maps prepared from the geochemical data show the distribution and abundance of selected elements, and summarize aspects of the regional geochemistry. Data from the Landsat Satellite Multispectral Scanner were used to compile maps showing the distribution of linear features and the generalized distribution of hydrothermally altered rocks.

Mineral deposits are widely distributed in the quadrangle, and include disseminated gold and other precious-metal deposits, molybdenum, tungsten, base-metals, mercury, and iron deposits, and nonmetallic deposits including magnesite, diatomite, and barite. The mineral resource assessment indicates that the potential for discovery of precious-metal and base-metal deposits is high in various parts of the quadrangle.

THE MINERAL INVENTORY PROJECT OF THE NEVADA BUREAU OF MINES AND GEOLOGY IN THE TONOPAH 1^{o} x 2^{o} QUADRANGLE

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The Nevada Bureau of Mines and Geology has conducted systematic mineral inventory investigations since 1979. This work has been funded largely by the Bureau of Land Management to gather mineral information to assist in their land-use planning. Contracts with the U. S. Geological Survey to gather data for MRDS (Mineral Resource Data Set) and with the Department of Energy for a mineral inventory on the Nevada Test Site have also aided the mineral data collection.

Work within the Tonopah 1^{o} x2^{o} quadrangle was done as part of three BLM mineral inventory projects; Shoshone-Eureka Resource Area, Esmeralda-Stateline Resource Area, and Tonopah Resource Area. Most of the Tonopah quadrangle falls within the Tonopah Resource Area. Field work in this area was done during 1985 and 1986. We have not worked in the part of the quadrangle that covers Mineral County.

The mineral inventory is completed in two stages. First, we conduct a comprehensive literature search and compile information on MRDS forms. Second, we visit every mining district within the project area and examine individual prospects and mines. We stress examination of small outlying properties as well as the well-known mines in order to expand information beyond that provided in current literature. Emphasis is placed on collecting basic geologic data on the mineral occurrences such as wall rock type, strike and dip of structures, and minerals present. Samples showing typical ore minerals are "high-graded" and usuallly taken from dumps, ore piles, or mineralized outcrops. These samples are not intended to be representative of ore grade material at the sites but are collected to investigate inter-element relationships in ores from the various mining districts within the state. The analytical work is done through a cooperative agreement between the Nevada Bureau of Mines and Geology and the U. S. Geological Survey.

All 33 recognized mining districts and areas within the Tonopah quadrangle were visited. We examined and described 314 mines and prospects and collected 372 mineralized samples for geochemical analysis. The results of this work are summarized in Nevada Bureau of Mines and Geology Open File Report 86-14. Maps showing mines, prospects, and sample locations and files with copies of our property examinations may be examined at the Nevada Bureau of Mines and Geology.

PRE-TERTIARY STRATIFIED ROCKS OF THE TONOPAH 1^{o} x 2^{o} QUADRANGLE

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Exposures of pre-Tertiary stratified rocks are scattered fairly evenly across the Tonopah 1^{o} x 2^{o} quadrangle and form about 15% of its total area. These rocks represent a variety of continental margin, ocean floor, and island arc depositional environments, and they record a complex history of tectonostratigraphic-terrane accretion onto the North American craton during Paleozoic and Mesozoic time.

The earliest accretionary events, respectively, in Early Mississippian and Triassic time, emplaced the Roberts Mountains and Golconda allochthons by thrusting them 100 km or more eastward over the continental margin. Both allochthons comprise a multitude of internally deformed thrust packets formed either of pelagic oceanic rocks, locally associated with pillow basalt, or deep-marine limestone and terrigenous clastic rocks related to the continental rise and slope. A popular model ascribes allochthon emplacement in each case to collision of east-facing island arcs with North America and interprets the allochthons as forearc subduction-accretion wedges. The present location of the arc rocks that would have been involved in these collisions is uncertain; they could have been either rafted away by some post-collision mechanism or buried beneath depositional or tectonic cover following subsidence owing to thermal contraction. In the Golconda allochthon, however, arc-derived upper Paleozoic volcanic and Paleozoic granitic debris occurs interbedded with pelagic sedimentary rocks, and supports the concept of eastward translation and eventual collision of an arc-related accretionary wedge.

Deformed lower Paleozoic continental slope deposits may represent the last off-scraped packets incorporated into the Roberts Mountains allochthon as it was obducted, according to the accretionary-wedge model. Thus distinction of such rocks from those that represent autochthonous or parautochthonous deep-water parts of the North American miogeocline is a matter of interpretation, and designation of lower Paleozoic rocks in the central part of the Tonopah quadrangle either as allochthonous or autochthonous remains controversial. Outcrops of clearly non-accretionary pre-Tertiary rocks--mainly shelfal lower Paleozoic and uppermost Precambrian carbonate rocks and orthoquartzites and upper Paleozoic clastic-wedge deposits and shallow marine carbonate rocks of the foreland of the Roberts Mountains allochthon--are generally restricted to the eastern third of the quadrangle. Sialic Precambrian crust, however, extends much farther west beneath the Roberts Mountains and Golconda allochthons, as indicated by the $[^{87}Sr/^{86}Sr]_o = 0.706$ isopleth that courses south and then bends abruptly west through the western part of the quadrangle.

Island-arc related Triassic and Lower Jurassic strata and associated upper Paleozoic andesitic volcanic and volcaniclastic rocks of the Walker Lake terrane crop out only west and north of the 0.706 line. These strata have no obvious sediment-provenance linkage with the continent until very latest Triassic time. Two deformations have affected the Walker Lake terrane during Middle Jurassic to mid-Cretaceous time. The ealier and most pronounced deformation resulted in hundreds of kilometers of NW-SE structural shortening, apparently related to underthrusting of the southern margin of the terrane by a westward projection of the continent. This episode of left slip with respect to North America was followed by NE-SW convergence, seen as the second major deformation in this part of the Walker Lake terrane. Convergent mid-Mesozoic structures in the mainly Paleozoic rocks to the south and east of the Walker Lake terrane are not yet adequately separated from earlier structures related to development of the Roberts Mountain and Golconda allochthons.

Pre-Tertiary tectonic history affects mineral deposits of the Tonopah quadrangle in three obvious ways: (1) it controlled the present distribution of rocks that have served as hosts rocks for mineral deposits; (2) structures formed that later provided controls on mineralization; and (3) the accretion and dispersal of terranes affected the bulk composition of the crust and thus any crustal influence on younger igneous materials to which ore-forming fluids might be related.

VOLCANIC ROCKS AND STRUCTURES OF TERTIARY AGE IN THE TONOPAH $1^o \times 2^o$ QUADRANGLE

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Volcanic activity commenced about 39-43 m.y. ago in the extreme eastern and western parts of the Tonopah $1^o \times 2^o$ quadrangle. In the east, this activity produced small volumes of rhyolite flows, intrusives, and related tuffaceous sediments. In the west, minor volcanism of intermediate composition produced small volumes of lava flows and local breccias. Outpouring of intermediate lavas and breccias, principally in the eastern and western parts of the quadrangle, continued until perhaps 34 m.y. ago.

At about 33 m.y. ago, explosive volcanism increased in magnitude across south-central Nevada. Large volumes of quartz latitic and rhyolitic ash-flow tuff were deposited across the quadrangle from 33 m.y. to about 22 m.y. ago. Several calderas that are prominent structures in the present mountain ranges formed during this period of intense pyroclastic activity. By approximately 17 m.y. ago, calc-alkaline pyroclastic eruptions ceased and volcanic activity was limited to outpouring of basaltic lava flows, principally in the western part of the quadrangle. Compared to the older pyroclastic rocks, volumes of these mafic flows are significantly less.

For the most part, the later part of the Tertiary period was a time of erosion and sedimentation in the Tonopah quadrangle. Local basaltic volcanism occurred in the Lunar Crater area and the northern Reveille Range.

Faults are the dominant Tertiary structures throughout the Tonopah $1^o \times 2^o$ sheet. As shown by the tilts of the Tertiary volcanic units, especially the ash-flow tuff sheets, there is a change in structural style across the quadrangle from east to west. In the east the Tertiary strata are mostly flat or only gently dipping. This includes the volcanic rocks in the Toquima Range and in the ranges to the east. Extreme tilts and complex structural relations are locally present in these ranges only near strike-slip faults, caldera margins, or occasionally Tertiary intrusive bodies. In the western part of the quadrangle, however, specifically in the topographically defined "Walker Lane" zone, structural relationships of Tertiary volcanic rocks are much more complex. Here tilts are commonly quite steep and the volcanic strata are often detached from pre-Tertiary basement rocks. Detachment faults separating steeply tilted Tertiary strata from underlying pre-Tertiary basement rocks have been recognized in the Royston Hills, Cedar Mountains, and Paradise Range. In addition, Tertiary sections in these areas display domains of tilt directions. For example, in the southern Cedar Mountains the ash-flow tuff section dips consistently to the west at moderate angles. Farther north, Tertiary strata dip steeply to the east. Domains of alternating dip directions in the ash-flow tuffs are often separated by domains of intermediate lava that may be either older or younger than the tuffs, domains of basement rock devoid of Tertiary cover, or fault zones now occupied by alluvial valleys.

GRANITIC ROCKS IN THE TONOPAH $1^o \times 2^o$ QUADRANGLE

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Granitoids that range from two mica garnet granite to diorite form about 60 plutons that crop out over about 375 km^2 in the Tonopah $1^o \times 2^o$ quadrangle.

Field, petrographic, geochemical, isotopic, and geochronologic studies of these granitic rocks and associated hydrothermal alteration and mineralization were made as part of the Tonopah CUSMAP project.

The oldest granitoids are small bodies of Triassic to Early Jurassic age that are exposed in an east-west belt in the southwestern part of the quadrangle. These rocks are K-feldspar megacryst-bearing granodiorites and quartz monzodiorites that crop out in the Monte Cristo Range, south end of the Royston Hills, and the San Antonio Range. The Fraziers Well pluton in the San Antonio Range yielded a hornblende K-Ar age of 221 Ma, making it one of the oldest plutons in Nevada. Mineralization associated with these intrusive bodies includes Ag-Pb-Zn replacement bodies in the Monte Cristo Range and W skarns in the San Antonio Range.

Cretaceous (102 to 80 m.y.), coarse-grained, locally megacrystic, biotite granites form the largest plutons in the quadrangle. They include the Lone Mountain pluton, granite of Shoshone Peak, granite of Pipe Springs, the main phase of the Ophir pluton, and several plutons in the Paradise Range. These granites are weakly peraluminous and locally contain muscovite and garnet, but they are all I-type granitoids. Parts of these plutons have strong NW-trending cataclastic foliations. Despite locally abundant quartz-muscovite-pyrite veins, relatively little mineralization is clearly associated with these plutons.

Late Cretaceous or suspected Late Cretaceous, locally porphyritic, hornblende-biotie granodiorites are widespread in the western half of the quadrangle but tend to form relatively small plutons. Major exposures are in the Paradise Range, north Cedar Mountain, Pilot Mountains, and Toiyabe Range. Mineralization associated with these bodies includes W skarns in the Pilot Mountains and north Cedar Mountain, Fe skarns in the Paradise Range and north Cedar Mountain, and polymetallic veins in the Paradise and Toiyabe Ranges.

Late Cretaceous granite porphyries containing quartz monzonite-type porphyry molybdenum occurs at the Nevada Moly (Hall) mine in the San Antonio Range and at the southwest end of the Paradise Range. The Nevada Moly mine is the largest mineral deposit that is clearly genetically related to granitic rocks in the Tonopah quadrangle.

Middle Tertiary granitoids (Eocene to late Oligocene) occur in the Toquima and Toiyabe Ranges and the south end of the Monitor Range. These bodies range from fine-grained, equigranular granodiorite near Round Mountain to porphyroaphanitic biotite granite on the east side of the Toiyabe Range. Mineralization related to these bodies is limited to polymetallic veins in the Toiyabe Range.

MESOZOIC AND CENOZOIC WALKER LANE STRUCTURES

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The Walker Lane belt is a northwest-trending zone about 700 km long and 100 to 300 km wide that is characterized by mountain ranges with unusual shapes or trends lying between the Sierra Nevada on the west and areas of north-northeast-trending mountains and valleys typical of basin-range topography on the east. Rather than consisting of a single throughgoing right-lateral fault or a system of right-lateral faults as indicated by many workers, the Walker Lane belt is a complex zone that can be subdivided into regional blocks of diverse character, including those with northwest-trending right-lateral strike-slip faults, those with northeast-trending left-lateral strike-slip faults, and those with few major high-angle faults. The Walker Lane belt appears to have been initiated in the Mesozoic, although latest movement on most of the faults is late Cenozoic in age.

The Walker Lane belt crosses the southwestern part of the Tonopah 1^{o} x 2^{o} quadrangle, where it is characterized by two unusual and enigmatic east-west-trending fault zones. These fault zones, the Excelsior on the north and the Coaldale on the south, are delineated mainly on the basis of faults in Cenozoic rocks and coincide with apparent major right-lateral offsets, totalling about 120 km, in the trends of Precambrian through Mesozoic rocks and of the line of initial 87Sr/86Sr = 0.706. These apparent offsets have previously been interpreted as the result of an original curving continental margin or tectonic distortion of originally linear trends by large-scale bending (oroflexural folding) or by crustal-scale folding related to northeast-southwest compression. Main offset on the Coaldale and Excelsior fault zones is considered pre-mid-Cretaceous because Jurassic sedimentary rocks appear to be offset whereas mid-Cretaceous plutonic rocks are not. These fault zones were locally reactivated in the Late Cenozoic, apparently with a reversal of the sense of movement, because Oligocene and Miocene ash-flow tuffs appear to be displaced 20 to 25 km left-laterally on the Coaldale fault zone. The Coaldale and Excelsior fault zones conspicuously disrupt the pattern of late Cenozoic faults in the Walker Lane belt. They mark the termination of major north-northwest-trending right-lateral strike-slip faults approaching the Coaldale fault zone from the south, and the termination of similar trending right-lateral faults approaching the Excelsior fault zone from the north.

GRAVITY AND MAGNETIC STUDIES IN THE TONOPAH 1^{o} x 2^{o} QUADRANGLE

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Preliminary regional aeromagnetic and gravity maps have been prepared at a scale of 1:250,000 for the Tonopah quadrangle. The aeromagnetic map was compiled as a mosaic of aeromagnetic maps from 11 aeromagnetic surveys. The gravity data consist of 3,200 measurements collected by the U.S. Geological Survey and 1,070 values obtained from the National Geophysical Data Center of the National Oceanic and Atmospheric Administration.

The aeromagnetic surveys were flown at elevations of 2,700 and 3,700 m above sea level (barometric) and at altitudes of 150 and 300 m above the average ground level. Flightline spacings were 0.8 and 1.6 km. Datum shifts were applied to the magnetic intensities of the previous surveys so that intensity levels would nearly match across survey boundaries. The aeromagnetic map reflects diversity in magnetization of surficial and underlying rocks. Pre-Tertiary sedimentary and volcanic rocks generally have low magnetizations and, consequently, are not sources of significant magnetic anomalies. Conspicuous magnetic highs with lateral dimensions that approach 10 km occur over outcrops and inferred locations of concealed Mesozoic plutons especially in the western part of the quadrangle. Many Tertiary volcanic rocks have high magnetizations, as indicated by strong correlations of magnetic anomalies with topography and the occurrence of negative anomalies over volcanic rocks that crystallized during a time of reversed magnetic field.

Special attention was devoted to improving the accuracy of terrain corrections, and doubtful locations in previous data sets were corrected or deleted during preparation of the Bouguer gravity anomaly map. An isostatic residual gravity map was prepared by estimating the effect of masses near the base of the crust, which compensate for topographic loads above sea level. Conspicuous gravity highs overlie mountain ranges and high-amplitude, elongate gravity lows overlie valleys. Prominent gravity lows over mountain ranges generally reflect calderas that enclose thick accumulations of low-density ash-flow tuff and sedimentary deposits. The shapes of some valleys and their associated gravity lows and the occurrence of adjacent thick accumulations of ash-flow tuff may suggest that calderas also underlie some valleys.

GEOCHEMICAL STUDIES IN THE TONOPAH $1^o \times 2^o$ QUADRANGLE

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Geochemical studies for the Tonopah CUSMAP project were designed to describe regional and deposit geochemistry and aid in resource assessment. Three sample media were utilized: 1) -60 mesh fraction of stream sediments, 2) nonmagnetic fraction of heavy-mineral concentrates from stream sediments, and 3) rocks. Stream-sediment and concentrate samples were collected at 1,224 sites, and rock samples were collected at more than 3,000 sites, generally where ore minerals or alteration was visible. All samples were analyzed for 31 elements by semi-quantitative emission spectroscopy. Stream-sediment and rock samples were also analyzed for As, Bi, Cd, Sb, and Zn, and some rocks for Au, Hg, Te, or Tl by atomic absorption spectroscopy.

Anomalous concentrations of base-and precious metals in stream-sediment and concentrate samples are widespread in the quadrangle, except in the Pancake Range. Interpretation of regional geochemical results is hampered by structural complexity that produces diverse lithologies in most drainage basins, and by the presence of several types of deposits that have overlapping chemical signatures. Multi-element anomalies are prominent in the Pilot Mountains, Monte Cristo Range, Paradise Range, Lone Mountain, northeastern Toiyabe Range, Cedar Mountains, and Toquima Range. As, Pb, and Sb in stream sediments provide good general guides to mineralization, and various combinations of Ag, As, Bi, Cu, Mo, Pb, Sb, and W in concentrates provide the basis for the interpretation of possible ore deposits types.

Base-metal enrichments in and near plutonic rocks are the most conspicuous geochemical anomalies. Two base-metal suites are commonly observed: 1) Bi + Mo + Pb + W ± As ± Sb ± Cu, and 2) the same suite minus Bi and W. These two suites are recognized in mineralized rock samples from deposits near plutons, with the Bi-W-bearing suite being characteristic of skarn-type deposits.

The regional geochemical signature in Tertiary volcanic terrane generally is one of low elemental concentrations with only a few elements such as As, Mo, Sb, or Zn reaching anomalous levels. The low amplitude of the anomalies and the small number of elements in the suite make interpretation of possible epithermal ore signatures difficult.

Reconnaissance lithogeochemical studies provide a database for characterizing mineralization in most deposits with significant production, and at numerous prospects. In my opinion the chief geochemical difference between the several types of precious metal deposits is the content of primary sulfide minerals, which often is reflected in base-metal content. The variation in base metal content (chiefly Fe, Pb, Zn, Cu) is consistent with the visible amount of iron oxides in samples from oxidized zones and increases with increasing iron oxides. The metal spectrum ranges from Ag-rich polymetallic deposits with high base-metal and sulfide content such as at Tybo, Reveille, Ophir, and Simon to gold deposits in silicified volcanic rocks such as Warrior, OMCO, and Gold Hill. Some Ag-Au deposits in volcanic rocks, such as at Gilbert and Divide, contain variable and often moderate amounts of base metals. The range in total metal content reaches its maximum levels in vein and skarn deposits associated with plutonic rocks. Deposits associated with plutons contain abundant As and Sb and many associated base metals, whereas in the volcanic environment As and Sb are often the most abundant metals, but are not generally accompanied by base-metal enrichments. Arsenic or As plus Sb are enriched in most ore enviromments and, like pyrite, are a useful guide to mineralization, but without other geologic or geochemical information they are not a reliable guide to a specific deposit type.

Published results of geochemical studies in the Tonopah region are listed below.

Fairfield, R. F., Jr., Siems, D. F., Zuker, J. S., Hill, R. H., Nash, J. T., and Budge, Suzanne, 1985, Analytical results and sample locality map of stream-sediment samples from the Tonopah 1^o x 2^o quadrangle, Nevada: U.S. Geological Survey Open-File Report 85-376, 85 p.

Hill, R. H., Siems, D. F., and Nash, J. T., 1986, Analytical results for stream-sediment samples from the eastern part of the Tonopah 1^o x 2^o quadrangle, Nevada: U.S. Geological Survey Open-File Report 86- [in press].

Nash, J. T., Siems, D. F., and Budge, Suzanne, 1985a, Geochemical studies of the Belmont silver district, Nye County, Nevada: U.S. Geological Survey Open-File Report 85-263, 19 p.

_____1985b, Geochemical signatures of ores and altered rocks from the Divide silver-gold district, Esmeralda County, Nevada: U.S. Geological Survey Open-File Report 85-535, 28 p.

_____1985c, Geochemical signatures of ore deposits and mineralized rocks from the Pilot Mountains, Mineral County, Nevada: U.S. Geological Survey Open-File Report 85-388, 22 p.

_____1985d, Geochemical signatures of ores and altered rocks in the Gilbert district, Esmeralda County, Nevada: U.S. Geological Survey Open-File Report 85-259, 21 p.

Nash, J. T., Siems, D. F., and Hill, R. H., 1985e, Geochemical signatures of ore deposits and mineralized rocks in the Cedar Mountains, Mineral and Nye Counties, Nevada: U.S. Geological Survey Open-File Report 85-260, 22 p.

Nash, J. T., and Siems, D. F., 198_, Regional geochemical maps of the Tonopah 1^o x 2^o quadrangle, Nevada, based on samples of stream-sediment and nonmagnetic heavy-mineral concentrate: U.S. Geological Survey Miscellaneous Field Studies Map MF-1877-B [in press].

Nash, J. T., John, D. A., Malcolm, M. J., Briggs, P. H., and Crock, J. G., 1986, Geochemistry of altered and mineralized rocks from the Morey and Fandango Wilderness Study Areas, Northern Hot Creek Range, Nye County, Nevada: U.S. Geological Survey Open-File Report 86-410, 52 p.

Saunders, J. A., Fairfield, R. F., Jr., and Siems, D. F., 1986, Analytical results and sample locality map for stream-sediment and panned-concentrate samples from the Fandango and Morey Wilderness Study Areas (NV-060-190 and NV-060-191), Nye County, Nevada: U.S. Geological Survey Open-File Report 86-196, 24 p.

Siems, D. F., Zuker, J. S., and Goldsmith, Kent, 1984, Analytical results and sample locality map of stream-sediment, panned-concentrate, and rock samples from the southwest part of the Tonopah 1° x 2° quadrangle, Esmeralda and Mineral Counties, Nevada: U.S. Geological Survey Open-File Report 84-121, 52 p.

Siems, D. F., Sharkey, J. D., and Tucker, R. E., 1986, Analytical results and sample locality map for stream-sediment and panned-concentrate samples from the Palisade Mesa and The Wall Wilderness Study Areas (NV-060-142/162 and NV-060-163), Nye County, Nevada: U.S. Geological Survey Open-File Report 86-113, 20 p.

Siems, D. F., Marchitti, M. L., and Nash, J. T., 1986, Analytical results for samples of nonmagnetic heavy-mineral concentrates from the Tonopah 1° x 2° quadrangle, Nevada: U.S. Geologicl Survey Open-File Report 86-213, 94 p.

MINERAL COMMODITIES IN THE TONOPAH 1° x 2° QUADRANGLE

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The Tonopah 1° x 2° quadrangle is particularly rich in diverse mineral occurrences that include base- and precious-metal, mercury, porphyry and skarn molybdenum, tungsten, and iron deposits and nonmetallic mineral occurrences such as magnesite, barite, diatomite, silica, and turquoise. The mineral occurrences mostly cluster into 40 mining districts, two-thirds of which lie in the western half of the quadrangle.

Seven districts yielded ten or more million dollars each, with as much as 300 million from Round Mountain. The large yields came mostly from precious-metals at five districts: Manhattan, Northumberland, Round Mountain, Tonopah, and Tybo. The San Antone district yielded molybdenum from a Mesozoic porphyry system, and the Gabbs district yielded chiefly magnesite, although the new FMC precious-metal deposit nearby should ultimately exceed the magnesite value. Only one of the seven districts, Tybo, lies in the eastern part of the quadrangle. Another six districts, mostly in the west, yielded ore valued at about two to five million dollars. These districts--Bell, Belmont, Divide, Lodi, Royston, and Union--produced mostly precious metals. The Union district also produced nearly one million dollars in mercury and Royston a high value in turquoise.

Base-metal silver deposits distinguished by their large dollar value of production include limestone replacement ore at Simon and Grantsville, vein systems in the Lodi, Belmont, and Union districts, and replacement ore at Tybo. All but Tybo are genetically associated with Mesozoic granitic plutons. Tybo ore occurs chiefly as replacement of Tertiary quartz porphyry.

Tungsten and molybdenum skarns and porphyries are more abundant than copper and occur in the central to western part of the quadrangle, where epizonal plutons are common.

Even though mineral occurrences are widely distributed, discreet areas devoid of mineral occurrences exist and are related to geologic features:

1) intermontane valleys and many dip-slopes of mountain ranges where thick relatively undeformed Tertiary ash-flow tuffs are common; 2) a large region in the extreme eastern part of the quadrangle that coincides with a series of coalesced Tertiary caldrons whose structures are partly exposed in basin-and-range blocks; 3) other caldrons, notably Arc Dome, Mt. Jefferson, and Kawich, with relatively barren cores rimmed by mineral occurrences; amd 4) segments of the 110 km-long northwest-trending Toiyabe-Kawich lineament.

Guides to the distribution of sediment-hosted precious-metal occurrences in the Tonopah quadrangle include sedimentary facies and their association with plutonism, volcanism, and structure. The factor emphasized is facies combinations. A consideration of suitable host rock and impermeable caprock sequences that may enhance localization of sediment-hosted, epithermal, precious-metal deposits indicates that the sequences are widely distributed and occur in four major assemblages of pre-Tertiary rocks in the quadrangle. The Paleozoic and Mesozoic strata over much of the region contain widespread facies combinations that are favorable for entrapping ore fluids and hosting ore deposits. Coincidentally, igneous events, including Mesozoic and Tertiary plutonism and volcanism evolved in spatial proximity to the various permissive facies, providing a source of fluids and heat to drive hydrothermal systems. Based on past discoveries of precious-metals concentrations associated with many of these igneous events, much of the Tonopah quadrangle is an exploration target for metals and especially gold and silver.

ASSESSING MINERAL RESOURCES IN THE TONOPAH 1° x 2° QUADRANGLE

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The mineral resource assessment of the Tonopah 1° x 2° quadrangle was made using the methodology developed for the Alaska Mineral Resource Assessment Program and consists of a quantitative, probabilistic estimate of the mineral endowment of the area. The assessment consists of three stages: (1) development or adaptation of descriptive and grade-tonnage models for deposit types that are known to occur, or may occur, within the study area, (2) delineation of areas permissive for the occurrence of selected deposit types using geologic, geochemical, and geophysical data, and (3) estimation of the number of deposits by deposit type that may occur within the delineated tracts. The assessment components and supportive geologic data are generally published in a disaggregated manner to allow reevaluation of the mineral resources as economic, technical, and socio-political conditions change.

As a first step in the assessment, known mineral deposits were classified into appropriate types. These deposit types include sediment-hosted gold-silver, hot-spring gold-silver, epithermal gold-silver veins, low-fluorine porphyry molybdenum, a variety of skarns, and several base-metal deposit types. The potential for additional deposit types such as porphyry copper deposits was identified through the occurrence of permissive geology similar to that found with deposits in other parts of the western United States. For each deposit type, a list of favorable criteria for occurrance was then compiled with an emphasis on those characteristics identifiable at a regional scale. Grade-tonnage models were then developed or adapted for most of the deposit types.

Tracts favorable for occurrence of undiscovered deposits were delineated for main deposit types, including gold-bearing deposits, skarns, porphyry copper and molybdenum, and polymetallic replacement and vein deposits. The tracts include areas in which undiscovered deposits may possibly occur within 1 km of the surface. Permissive rock has the strongest influence in determining tract boundaries, but known mineralization, appropriate alteration, geophysics, anomalous geochemistry, and other factors may alter those boundaries. Lack of data does not exclude ground from the tracts, rather ground tends to be included unless sufficient data exist to confidently exclude an area.

Results of the assessment indicate that there is a 90% chance that additional sediment-hosted gold-silver, polymetallic veins, epithermal gold-silver veins, and low-fluorine porphyry molybdenum deposits are likely within the quadrangle. In addition, we estimate that there is a 50% chance that at least one additional deposit is present for all of the major metallic deposit types that were evaluated for number of undiscovered deposits. Potential mineralization related to intermediate to felsic intrusive rocks is largely limited to the western part of the quadrangle, but areas of potential precious metal deposits are distributed throughout the quadrangle.

COMPUTATION OF NUMERICAL ESTIMATES OF THE UNDISCOVERED GOLD AND SILVER ENDOWMENT CONTAINED IN FIVE TYPES OF MINERAL DEPOSITS IN THE TONOPAH $1^{\circ} \times 2^{\circ}$ QUADRANGLE

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A computer simulation program designed to assist in the mineral assessment process makes it possible to formulate an assessment consistent with a variety of conditions by calculating successive examples of realizations of endowments that exhibit the range and statistical dependencies of metal grades and ore tonnages believed by experts to hold for the area.

Five characteristics of the undiscovered gold and silver resource were estimated. These characteristics include the types of gold-bearing deposits expected to occur, the frequency distribution of the number of deposits of each type, the frequency distribution of the grades of each metal in the deposits, the frequency distribution of the ore tonnage for each deposit, and the mean metal content for each deposit type. The lognormal distribution was used for both ore tonnages and metal grades except in the case of the grade of gold in hot-spring gold deposits, where a normal distribution was used.

The program determined a correlation between log(tonnage) and log(grade) so that the expected value of the product of grade and tonnage was the mean metal content. No dependencies between the various metal grades were considered. The distribution of the number of deposits was specified by giving an "at least" number for three different probablilities 10%, 50%, and 90%. Although this doesn't completely determine the distribution, the program was written to choose a distribution of the number of deposits consistent with the "at least" constraints.

The five types of gold-bearing deposit types believed to occur in the Tonopah area are hot-spring gold, carbonate-hosted gold-silver, polymetallic replacement, polymetallic vein, and epithermal gold-silver. The majority of the gold was estimated to occur in the carbonate-hosted gold-silver, hot-spring gold-silver, and epithermal gold deposits. Silver was estimated to occur mainly in the polymetallic vein and epithermal gold deposits. The expected undiscovered gold and silver endowment was estimated to be 210 metric tons of gold and 8200 metric tons of silver.

DIGITAL SPATIAL DATA ANALYSIS FOR MINERAL RESOURCE ASSESSMENT OF THE TONOPAH 1° x 2° QUADRANGLE

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A geographically referenced digital database for the Tonopah quadrangle was developed as a demonstration of digital procedures for multivariate spatial analysis. The database includes stream sediment geochemistry, a 1:250,000-scale generalized geologic map, mineral occurrence data, distribution of limonite interpreted from Landsat satellite data, digital elevation models, and drainage basins specific to stream sediment sample locations. The objectives were to evaluate quantitative spatial relationships between data sets as criteria for mineral deposit-type occurrences.

Methods of analysis ranged from simple overlays of data sets to delineation of areas favorable for skarn-type mineralization and analysis of geochemical data related to different epithermal environments. Basic data manipulations consisted of overlaying various data to display their spatial relationships. For example, pre-Tertiary intrusions and Paleozoic sedimentary units were displayed on a shaded-relief base overlain by locations of mineral occurrences where silver is a commodity. Stream sediment geochemical data were represented as interpolated surfaces modified to show areas with anomalous concentrations of specified elements.

Another task was to define areas favorable for the development of skarn mineralization. Stream sediment and pan concentrate analyses for Bi, Mo, Pb, and W were interpolated and combined to show their spatial association at levels above background concentrations. A lithologic submodel was then developed to isolate areas where carbonate-rich sedimentary rocks exist within a two km radius of exposed plutons.

A third problem addressed the difficulty of separating geochemical signatures of volcanogenic epithermal environments from those of plutonic sources. Drainage areas, geology, and geochemistry were geographically referenced and linked by common attributes to select basins for analysis. A high concentration of Ag, Sb, and As in association with Mo and low levels of Bi, Pb, and W were considered representative of epithermal mineralization and these basins could be extracted and spatially compared with basins where over 50% of the mapped area is composed of Tertiary volcanic rocks. Modification of these areas could be achieved by adjustment of geochemical threshold or based on the presence of specific geologic units or the occurrence of limonite.

The complexity of the analyses that can be performed depends on the data available and the definition and relationships of criteria to be investigated. These capabilities facilitate iterative testing of working hypotheses and models. The results can be used to generate cartographic products supplemented by statistical summaries. Although diagnostic criteria for many deposit types can be defined, the task of merging and integrating them is cumbersome if manual overlay is required to isolate areas where composite indicators are superposed.

GEOLOGY OF TERTIARY VOLCANIC ROCKS IN THE PARADISE RANGE AND NORTHERN PACTOLUS HILLS, NYE COUNTY, NEVADA

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Detailed mapping of Tertiary volcanic rocks in the Paradise Range and the northern Pactolus Hills and new K-Ar dates by E. H. McKee indicate a complex history of middle to late Tertiary volcanism, tectonism, alteration, and mineralization. Thick sections of ash-flow tuffs, intermediate lavas, and minor volcaniclastic sedimentary rocks crop out on the north, east, and southwest sides of the range. Tuffs on the southwest side do not correlate with those on the north or east sides, and only a few units are common to both the north and east sides. Ash-flow tuff sections from the southwest and east sides of the range are juxtaposed by a high-angle fault in the northern Pactolus Hills.

Rhyolitic ash-flow tuffs at the north end of the range are locally intercalated with andesitic flows near the base of the section. The flows and most of the tuffs increase in thickness to the north, and most of these units are absent south of Sherman Peak. Contacts between Tertiary and pre-Tertiary rocks are faults. The tuffs are tilted 30°-70° NE or SE. Au-Ag mineralization in the Ellsworth district occurred along NW-trending faults where they intersect the basal rhyolite tuff. These faults locally cut high angle fault contacts between Tertiary and pre-Tertiary rocks, and mineralized jasperoids are locally present along these structures.

On the east side of the range, Oligocene and early Miocene ash-flow tuffs are unconformably overlain by Miocene andesitic and trachyandesitic lavas. The upper half of the tuff sequence is about 22-26 Ma. The tuffs are generally tilted 30°-40° E and are overlain by intermediate lavas that dip about 15° E. The age of the angular unconformity is bracketed between about 22 and 19 m.y. All contacts between Tertiary and pre-Tertiary rocks are faults, and both high angle and low angle structures were recognized.

On the southwest side of the range, andesites and dacites about 24-25 Ma are overlain by ash-flow tuffs about 24-22 Ma. The tuffs are overlain by andesites, dacites, and quartz latites about 20 to 15 Ma. Silicic dikes and domes that cut all these sections are mostly 16-17 Ma. The Tertiary rocks are separated from pre-Tertiary rocks by a low-angle fault that dips gently to the SW. Tuffs in the upper plate are steeply rotated and dip 40°-90° NNE. Other low-angle faults within the Tertiary rocks cut faults that are parallel to bedding planes that have been rotated to high angles. The low-angle faults are cut by E-W faults and NNE-trending Basin and Range faults. Dating of rhyolite dikes intruded along faults suggests that low-angle faulting and some E-W faulting occurred about 16 Ma.

Gold, silver, and mercury at the Paradise Peak mine occur in a rhyolite tuff near the base of the tuff section. Tuffs in the vicinity of the mine are unusually thin and only gently tilted. Low-angle faulting has not been recognized. Mineralization is about 18 Ma and is contemporaneous with andesitic to quartz latitic lavas.